SUMMARY

This report presents an analysis of the VerseFx noise problem and describes other aspects of the system.

A plan of action in two steps is proposed: The first step is to reach a Scanimate-like signal performance level, and the second step is to improve upon it.

1. Analysis of the noise problem.

   We have established that most of the noise comes from the scanning process. A noise measurement system is set up, and a device duplicating the scanning-to-video noise transfer mechanism is designed. A separate measurement of the video S/N impact of a given noise source in the scanning path is now possible.

   S/N measurements of present VerseFx give, in the worst case, a 24db figure (corner of the screen, peak white). This result is not due to a single cause, but to a multiplicity of noise sources located in the VRG, VRM and VCR boards.

   Most noise sources are random and wide-band, and non-random interferences, due for example to switching regulators, fast switching transients, poor grounding, etc. are secondary. The overall rack structure is therefore not to be significantly modified and we should limit ourselves to intra-board changes.

   The most important sources of noise are the perspective dividers, but multipliers and operational amplifiers also contribute to the noise make-up. Their noise has no theoretical reason to be at that level, and is due to poor circuit design practices.

   This point is further enhanced by designing a simple rotation multiplier capable of operating with a 57db S/N.

   We then propose to solve the noise problem by:

1. Implementing a partly digital solution for the perspective dividers and:

2. Replacing all multipliers and operational amplifiers by simpler structures, based upon the same building block. (To be designed.)

In order to reach a 40db S/N at the output of the VerseFx, the video-equivalent S/N of this building block is to be above 60db.

No change in the basic structure of the VerseFx rack is necessary (except for use of shielded wires for certain connections).

2. <u>Other aspects of the system</u>.

We have analyzed the entire system and compared its structure, functions and performances to those of Scanimate and System 4. The overall poor signal performances of Scanimate :36db S/N, shading, low resolution, have been a surprise, and our examination of System 4 show also a poor subjective picture quality. It is therefore, our opinion that Rescan systems capabilities have not been fully exploited in Scanimate and System 4.

We also found the control system of VerseFx superb, and far superior to the System 4 approach. VerseFx, however has the same problem of poor video intensity tracking as Scanimate, a problem which will not be quickly solved, short of a new invention.

Gamma, black level stability, shading, field uniformity, are also mediocre but can be improved by simple circuit hygiene and component selection. Resolution is marginal at the present time, but can easily be extended, and the Rescan configuration is adequate (blue phosphor CRT, plumbicon tube).

3. <u>Plan of action. First step</u>.

This step represents the minimum action required

to make the system marketable. A more restricted effort would lead into wasted engineering. There should be no differences between the SFP and the Image West systems and improvements, in the interest of time and simplicity.

Upon completion of this step, overall video performances should be equal or better than those of Scanimate. We hope to achieve, in particular, a much better S/N ratio. This first step is to be executed in two phases, overlapping in time:

A. First Phase.

   End product: One Rescan rack with hand-wired piggy-back modules mounted on VRG, VRM and VCR boards, plus one extra set of hand-modified boards.

   This rack should be operational with the required performances and could be sent to the SFP with a master chassis and a control desk.

   Delivery: 4 1/2 months plus or minus 1 1/2 month.

   Cost: Approximately $100,000, including outside labor and parts, Faroudja Laboratories expenses, but not including Image West and SFP salaries and overheads.

B. Second Phase.

   End product: Two full systems (4 + 3 Rescan racks) having the same performances as the prototype rack, but with finalized boards.

   Delivery: Nine months from time 0.

   Cost: Approximately $70,000 including Faroudja Laboratories expenditures, outside labor and parts, but not including Image West and SFP salaries and overhead.

4. Plan of Action. Second Step.

The purpose of this plan is to improve VerseFx to the point of not distinguishing its picture characteristics from those of digital systems, (Ado, Mirage) while retaining its extreme speed of execution and its programming simplicity. Briefly, it is to design a tool capable of Mirage-like image manipulation with much simpler and quicker operating and programming procedures.

Improvements should be incorporated one at a time; and without affecting the overall circuit architecture. In order of priority, these steps are:

A. Install a monitor at artwork camera and improve Rescan CRT viewing.

B. Implement video intensity tracking by using feedback from the CRT screen: the method is yet to be invented.

C. Use proprietary Faroudja enhancement and noise reduction processes.

D. Make each channel full color by using time-multiplexing and digital memories.

E. Digitalize all scanning waveforms generations and manipulations and finally, digitalize the Rescan device itself.

August 3, 1984

VERSEFX PROJECT

REPORT ON JUNE-JULY ACTIVITIES:

PLAN OF ACTION

A. Introduction.

B. Noise Problem.

   1. Scanning noise mechanism.
   2. Noise measurement setup.
   3. Noise levels and comments.
   4. Simulation.
   5. Conclusion.

C. Other Aspects of the System.

   1. Controls.
   2. Scanning bandwidth.
   3. Video amplitude tracking.
   4. Miscellaneous.
   5. Scanimate and System 4 references.

D. Proposed action.

E. Long Term System Optimization.

A. Introduction.

The work described in this report has been carried out by Jim Ryan, Bill Schultz and myself, following acceptance by Image West and by the SFP on my June 14, 1984 proposal, and represents the execution of the first phase of our plan of action (page 5 of the June 14, 1984 report).

Our activities can be summarized as follows:

1. Scanning noise has been analyzed, understood and its sources have been located.

2. A noise meter specifically adapted to the task has been developed, and has been used to measure noise levels in areas under scrutiny.

3. A simulation using a new multiplier has been performed in order to illustrate the S/N capabilities of the Rescan system and a demonstration tape has been recorded.

4. Other characteristics of the system: video amplitude tracking, CRT/Rescan camera performances, control system, have been analyzed. Scanimate and System 4 performances have been observed.

5. As a conclusion, a plan of action for reaching marketable conditions, as well as a long term improvement program, are presented in this report.

B. Noise Problem.

1. Scanning noise mechanism.

We had previously identified (June 14 report) noise as being mostly caused by horizontal and vertical scanning. It is therefore mandatory to understand and quantify the mechanism of transfer of scanning noise into video, as it appears on the Rescan CRT faceplate. A simple

way to analyze the effect of noise is to add a sine-wave to the scanning waveform and to observe the re-scanned video on an oscilloscope (figures 1 and 2).

In these conditions, our measurements show that:

A. At low levels, the video noise is proportional to the first order derivative of the scanning noise (6db/octave).

B. At higher levels, the video noise responds in a non-linear fashion to the scanning noise (photo no. 2). Noise peaks tend to be narrowed, while dark areas are wider.

C. For a given scanning noise, the video noise level will be roughly proportional to the grey level, except for areas of CRT extreme non-linearity (black). As a result, the video S/N (always computed by reference to peak white) will always be better in dark areas of the picture.

These effects are easily understood if one considers the spot trajectory on the CRT faceplate. First of all, better S/N's in the dark areas are obvious: If there is no light, CRT spot velocity changes have nothing to modulate and there shall be no noise. However, in clear areas, spot velocity does matter: If the spot is stationary or slowly moving, the CRT light level will quickly reach saturation in one point. If the spot is rapidly moving, the screen will remain dark.

If gamma is unity, (which is a very rough approximation in the case of the Rescan system, figure 9) the Rescan camera electrical output is proportional to the spot intensity, (Rescan video in) multiplied by the plumbicon integration time, that is, inversely

proportional to spot velocity. As the velocity is proportional to the scanning frequency, a 6db/octave noise transfer wave is to be expected at low noise levels, and is confirmed by experience. At higher noise levels, the sawtooth begins to look like a staircase (figure no. 2) which explains alternations of white narrow peaks and large dark areas.

Table 1 gives an idea of noise transfer levels for an horizontal sawtooth (15KHz) having a S/N of 50db, o a uniform peak-white video.

Signal = V peak to peak/non composite video
noise = VRMS

Scanning noise frequency KHz	Video S/N db
15	46
30	40
60	34
120	28
240	22
480	16
960	10

Table 1

Average transfer for white noise in a 500KHz bandwidth--50db scanning = 20db video

The conclusions are:

A. Scanning waveforms must have a very high S/N. The vertical sawtooth at 50 or 60Hz is more sensitive to noise than the horizontal, as its bandwidth extends over 13 octaves for the horizontal.

B. It is desirable to reduce scanning

bandwidths as much as possible. 500KHz is a resonable compromise = good linearity, (even in the high resolution mode) acceptable rise time (1us) for the rarely used "hole punching" effect, and reasonable noise (photographs 5 and 6).

C. The output bandwidth of the analog oscillator boards is to be limited. In particular, triangular or square waveforms (see figures 3 and 4) have to be low-pass filtered in order to make video intensity tracking practical.

D. A measuring tool to simulate the effect of scanning noise upon video is essentially a first order differentiator, with two switchable time constants, for horizontal or vertical applications.

   Such a device is, however, very imprecise for video S/N ratios lower than 30db because of the non-linear nature of the transfer, and above 60db, because of its own input noise level.

2. Noise measurement set-up.

Figure 34 shows the overall diagram of the set-up. Figures 35 and 36 represent the block diagram and the schematics of the scanning-noise to video-noise transfer simulator.

The simulator input level is always calibrated at 0.5Vpp. The DC balance is to be adjusted for minimizing tilt and offset at the Rhode and Schwartz noise meter input.

In these conditions, we will measure the effect of scanning noise onto video with a plus or minus 1db precision in the 30 to 60db range, as preliminary calibration with the device and video noise itself show.

3. <u>Noise Levels</u>.

Results of the measurements are as follows:

Scanimate (reference)		black:	45db
		white:	36.5db
VFX full system	center	black:	40db
	center	white:	28db
	corner	black:	40db
	corner	white:	24db

<u>VFX noise sources</u>. All measurements are done with a peak-white field, excluding extreme corners and effects (shading, tilt) not related to noise, in a 100KHz to 4.2MHz bandwidth.

These measurements are performed at the Rescan camera output and/or with the scanning-to-video noise transfer simulator.

In these cases, transfer is supposed to take place to a peak white field. All geometrical functions are at their nominal center value.

VFX NOISE SOURCES

		Figures
Rescan	45db	12
VID board	43db	
H & V scanning (VRG,VRM & VCR)	28.5db	
H scanning	33db	21
V scanning	30db	22
VRG V	44db	
H	48db	
VRM V	44db	
H	47db	
VCR no perspective V	36db	
H	38db	
VCR with perspective V	31db	
H	32db	
Overall VFX	28db	19-17, 19-20

A few comments are in order as far as the noise problem is concerned:

A. The Rescan CRT/camera combination does not significantly contribute to the total if both CRT and camera are properly aligned. There is, however some non-random interference at 200KHz and at about 46db (figure 11), which has to be either eliminated or "hidden" by selective coring.

B. The VID board is not a significant source of noise.

C. There are very few coherent interferences in the makeup of scanning noise, as both show a continuous noise spectrum for nearly all measurements. Interferences due to switching regulators, excessively short rise-time on digital waveforms, and poor overall circuit layout are presently masked by purely random effects.

   Interferences might, however, appear when the major noise defects are corrected, but spectral analysis of the different noise sources clearly indicate that if they exist, they are in the -45db range or better. We should therefore, not worry about the basic structure of the Rescan rack, and simple shielding of sensitive areas or scanning waveforms interconnections between the VRG, VRM and VCR board may suffice.

D. There is no theoretical justification for these excessive noise levels. An amplifier with a 6db noise figure and a 1Kohm input impedance and connected to a 5Vpp, 15KHz sawtooth in a 500KHz bandwidth should have a S/N given by:

resistor thermal noise

$$E = \sqrt{2RKT\Delta F}$$

with $K = 1.38\ 10^{-23}$ J/K
$T = 300^{\circ}$ K
_F = 0.5 10^{6} Hz
R = 1000 ohm
E = 2mv RMS

Amplifier input noise

N= 2E = 4mv RMS

Scanning waveform

S/N = 122db

Equivalent video S/N as per Table 1

122 -30 = 92db

Even with 40 independant noise sources having the same characteristics, the output S/N should be:

S/N = 92db -10 log 40

S/N = 76db

Therefore, the excessive noise is due to mediocre analog design, poor choice of components and a lack of understanding of noise problems. Three components of the system are particularly mediocre: The multipliers, operational amplifiers and logarithmic amplifiers.

E. Multipliers. The 429 multipliers, selected because of their 10MHz bandwidth (which is unnecessary) are extremely noisy by construction (600mv RMS input noise) but even noisier in the present configuration.

The Harris 2535 operational amplifiers, (which have been discontinued) are a very significant noise source. The structure, and the values chosen for gain control components, lead to a very low input level with a very high impedance (10K ohm) as seen at the op-amp input, a situation which is not favorable to noise.

Furthermore, the bandwidth of these amplifiers (as utilized in VFX) is only 150KHz (figures 27-28) which is absurd as they follow a 10MHz multiplier.

Finally, the method selected for the perspective dividers: transformation of Z into 1/Z by logarithmic amplifiers and multiplication of H or V scanning waveforms by 1/Z is possibly the noisiest one can conceive.

The 1/Z noise at the output of the logarithmic amplifiers for the nominal Z value is 30mv RMS.

This is particularly dangerous as the Z signal itself is submitted to large variations, and this noise may be magnified for extreme perspective cases. In any instance, it wll be necessary to reduce the presently excessive perspective range.

4. Simulation.

Figure 34 shows a multiplier capable of generating rotation around a horizontal or

vertical axis.

The multiplier itself has, for a 3MHz bandwidth, a video noise transfer equivalent S/N of 57 db.

The overall VFX output S/N is 46db in the black areas and 43db in the white areas if only this new multiplier is used, and used only for vertical rotations (figures 30 and 31).

The VRG, VRM and VCR boards are to be significantly modified to improve S/N ratios. Each board should by itself show an equivalent video S/N of 57 to 60db for each scanning waveform.

To reach this goal, a low noise building block is presented on figure 38. This circuit should be capable of additive or multiplicative manipulations of a scanning waveform with a video-equivalent S/N better than 60db.

The situation, on a board to board basis, is as follows:

<u>VRG</u>

Detailed measurements of equivalent video S/N ratios.

<u>Horizontal</u> (150KHz bandwidth)

1. as it is: 48db
2. with 632 multipliers; and all resistors divided by 10: 52db
3. same, without multipliers: 57db

Vertical (150KHz bandwidth)

1. as it is: 44db

2. with 632 multipliers; and all resistors divided by 10: 50db

3. same, without multipliers: 52db

These figures are nearly acceptable. It is not obvious whether the structure should be drastically modified or not. The best course of action is to attempt to live with the present ramp generators, replace op-amps by our noise-free adder (figure 38) and replace the multipliers by MC1595 types. All connections to and from the analog section are to be shielded and power supplies are to be decoupled (these conditions apply for all three boards).

VRM. Our experiments with the present structure only allow us to improve the 44-47db figures to about 47-50. Furthermore, when a rotation takes place, three multipliers are being used in each channel, and the final S/N may be even lower. 429 multipliers and HA2535 operational amplifiers are, therefore, to be replaced by figure 38 building blocks. Shielding of analog circuits and connections is required.

VCR. 429 multipliers and HA2535 operational amplifiers are to be replaced by figure 38 building blocks.

The logarithmic amplifiers are to be replaced by a digital solution; a 12 bit 1.5MHz clock rate encoding process is sufficient for a signal having a bandwidth of 500KHz and a video-equivalent S/N of 53db at nominal perspective level. It is to be noted that the perspective range is to be reduced, and, in the worse case, the magnification should not exceed a value of 4.

The S/N in the worse case of perspective becomes only 41db.

It is to be noted that the ADO itself does not work properly for magnifications exceeding a ratio of 4 (aliasing) and that, in practice, excessive perspective is unnatural and not very usable from an artistic standpoint.

C. <u>Other Aspects of the System</u>.

1. <u>Controls</u>. We find the control system design superb, and the operation of VerseFx from the control desk can be learned very quickly.

   The concept of a central menu and of 4 half screens displaying full information at all times is very practical, and real time manipulation through joysticks feels very natural.

   However, some minor flaws should be quickly corrected:

   A. X and Y axis are inverted on one of the joysticks.

   B. Perspective control is acting too quickly.

   C. The rotation axis location should be immediately evident and visually displayed on the output monitor.

   D. A push button return-to-zero-axis locator would be useful.

2. <u>Scanning bandwidth considerations</u>. As we stated earlier, a 500KHz scaning waveform bandwidth is adequate from a linearity point of view. We believe that it is also adequate from an image manipulation standpoint. The only practical case of use of large scanning bandwidth is the "hole punching" effect, rarely used. With a 500KHz bandwidth, the "hole" boundaries will have a 1μs equivalent width, which is sufficient. One must remember

the price to pay for increasing the bandwidth, as the video noise is proportional to the first derivative of the scanning noise: If the noise is white at the sawtooth, and if the bandwidth is doubled, scanning S/N degradation is only 3db, but video S/N degradation will be 9db.

3. Video amplitude tracking. Figure 2 clearly shows the impracticality of open loop video amplitude tracking. This is confirmed by the poor performances of both Scanimate and System 4 in that respect. The VID board is to be considered as a very rough approximation of what is necessary, but fulfills an essential function of protecting the CRT from irreversible burn-ins.

   I do not propose to do anything about it in the first phase of rework. I would, however, suggest to limit as much as possible (under 500KHz) the analog oscillator bandwidths.

4. Miscellaneous.

   A. Documentation. Quite insufficient. Schematics are either incomplete or out of date. I sugggest to select a single set of blue prints for schematics, update them by hand to reflect the present VerseFx status, then keep using this single set for continuing updating until the design is completed.

   B. Rescan area. Noise characteristics have been found adequate (figures 11-12).

      However, response, linearity, field uniformity and shading should be improved (figures 9, 10, 13, 14). Part of the problem is due to the fact that we are using an older CRT, and we did not want to replace it at this stage because of cost. Simple circuit hygiene and use of a new tube should make these performances adequate.

A problem of black level stability: good if the CRT chassis input is connected to the VID board (whose output shows sync compression) and bad if it is connected to a clean signal from a generator, deserves a full investigation.

C. Other boards. Master chassis. The operation of other boards of the system has been thoroughly described to me by Jim Ryan and no particular attempt to examine at length their performance has been made.

The system structure appears to be logical and quite straight forward, with the exception of the flying spot rack, whose function is not clear to me.

5. Scanimate and System 4.

A full investigation of Scanimate has been carried out (photographs 23, 24-26, 32, 33) and its performances have been found surprisingly mediocre: 36db S/N, shading, low resolution, poor video intensity tracking.

Apparently the animators can live with these problems and somehow find a way to go around it (through quantization, or use of lower grey levels only) at the expense, I suspect, of time necessary to carry out a project.

According to the main users of the system, Sonny King and Peter Koczera, Scanimate is still quite useful in relation with ADO as it has texture, shading and glow capabilities. They would like to have a system with better picture quality, some perspective and 3-D functions (they can "fake" it with ADO) but mostly computer control and disk storage capabilities. VerseFx should be such a system.

System 4 did not appear to be better than Scanimate from the S/N viewpoint and its computer controls look akward and antiquated by comparison to VerseFx.

D. Proposed action. As shown on figure 39, I envision two phases of execution of the project:

1. The first phase, which will take 4 1/2 months (with a possible error of plus or minus 1 1/2 month) will end up with one Rescan rack, operating with performances equal or better than Scanimate and will include hand-wired piggy-back boards, to be mounted on existing VRG, VRM and VCR boards.

   A second set of hand-modified VRG, VRM and VCR boards should be also built. The first Rescan system could then be sent to Paris (together with the master chassis and the control deck) while the extra set of boards could stay at Image West, to be used as a reference for alignent of actual P. C. boards.

2. The second phase, which will take about eight months, and which will overlap in time with the first one, wll result in two full systems operating at the Scanimate performance level or better, and making use of relayed P. C. boards. The SFP unit could be progressively updated, one board at a time, and completed with three extra racks at the end of that phase.

   The cost for the first phase would approximately be $100,000 while the cost for the second phase would approximately be $70,000. These figures do not include IW and SFP employees salaries and overhead. This estimate is based upon availability of key personnel from Image West and the S.F.P.

E. <u>Long Term System Optimization</u>.

The purpose of this optimization program is to improve VerseFx to the point of not distinguishing its picture characteristics from those of digital systems, (ADO, Mirage) while retaining its extreme speed of execution and its programming simplicity.

Improvements should be incorporated one at a time and without affecting the overall circuit architecture. Certain portions of these improvements could be in fact implemented now, without having an impact on the first step of redesign. In order of execution we should consider these steps:

1. Install a monitor at the output of the artwork camera for ease of alignment, and a viewing device (semi-transparent mirror?) giving an easy visual access to the Rescan CRT faceplate.

2. Replace Cohu cameras by better models.

3. Use synchronous spot wobulation at the artwork camera and display CRT to eliminate Rescan bar in the low resolution mode, and maybe to reduce the need for a high resolution mode.

4. Implement a form of closed-loop video intensity tracking. This technique is yet to be invented.

5. As soon as the S/N is better than 40db, make use of Faroudja Laboratories proprietary enhancement and noise reduction techniques.

6. Make a single Rescan channel capable of full color processing by using a time-multiplexing and digital memories approach.

7. Digitalize scanning waveform generation and manipulation and possibly, as a final step, the Rescan device itself.

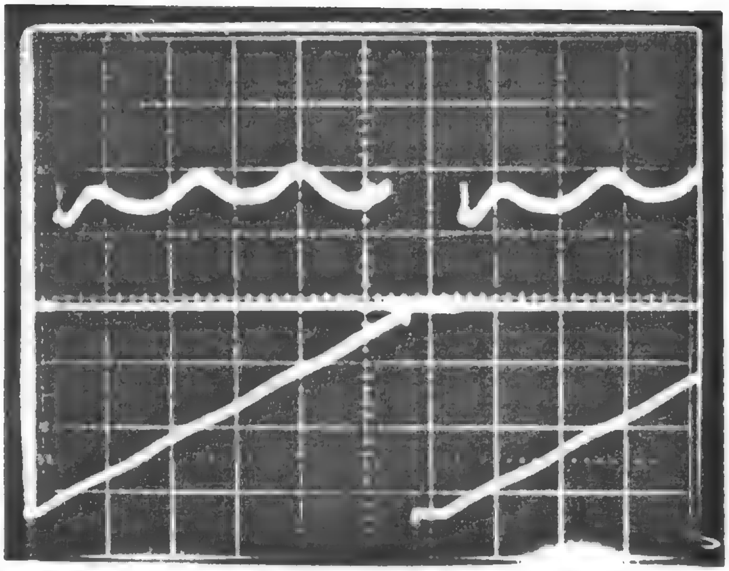


FIG. 1

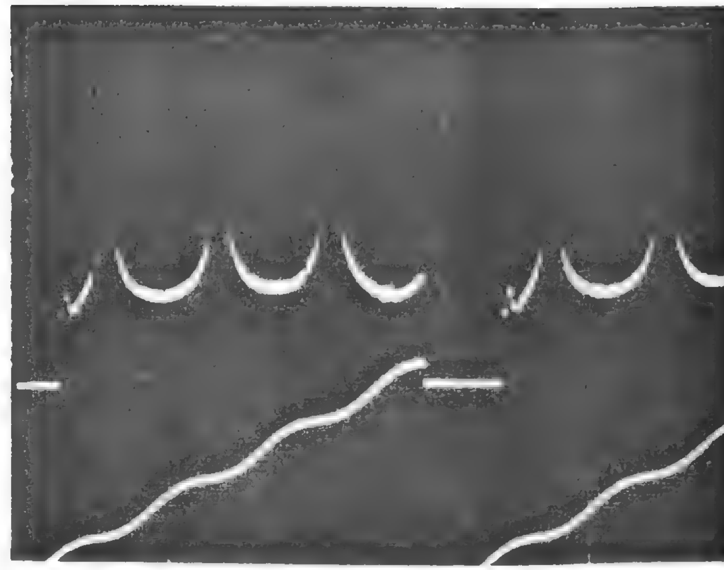


FIG. 2.

FIG. 3

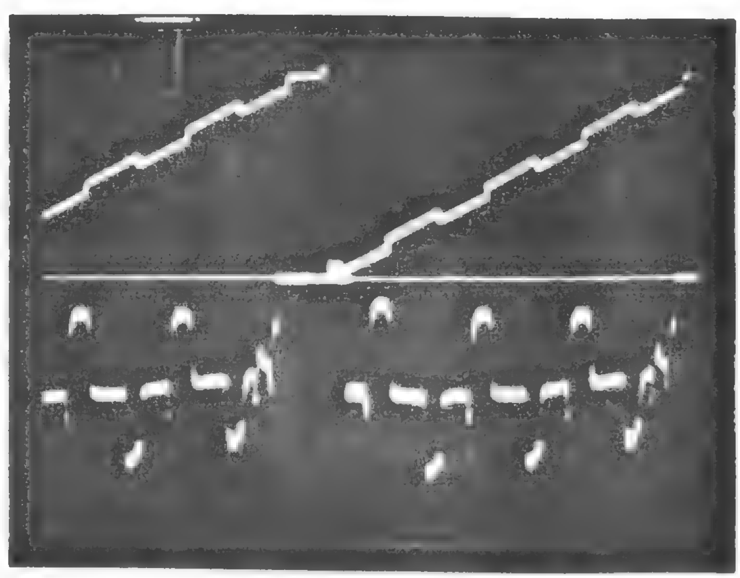


FIG. 4

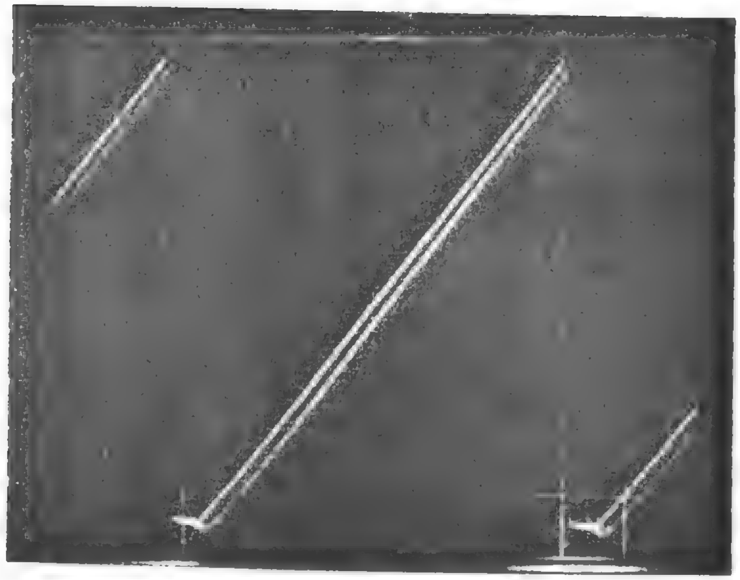


FIG 5.

15 kHz SAWTOOTH WITH 200 kHz LPF.

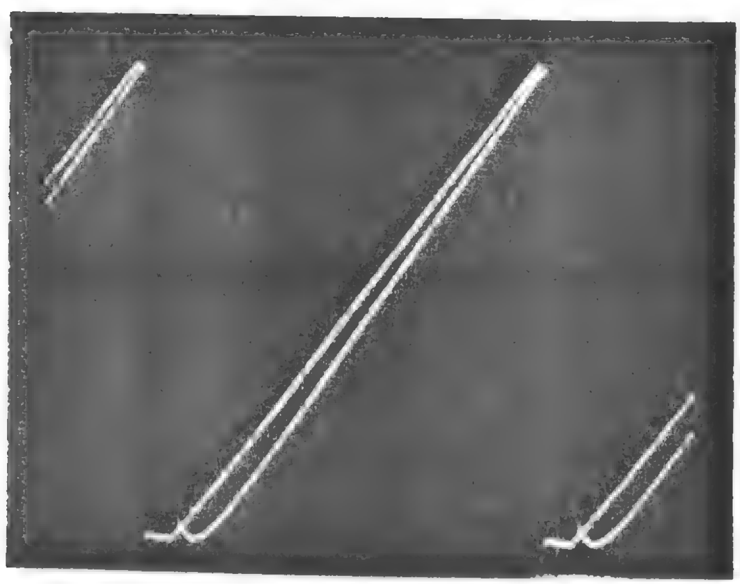


FIG. 6.

15 kHz SAWTOOTH WITH 100 kHz LPF.

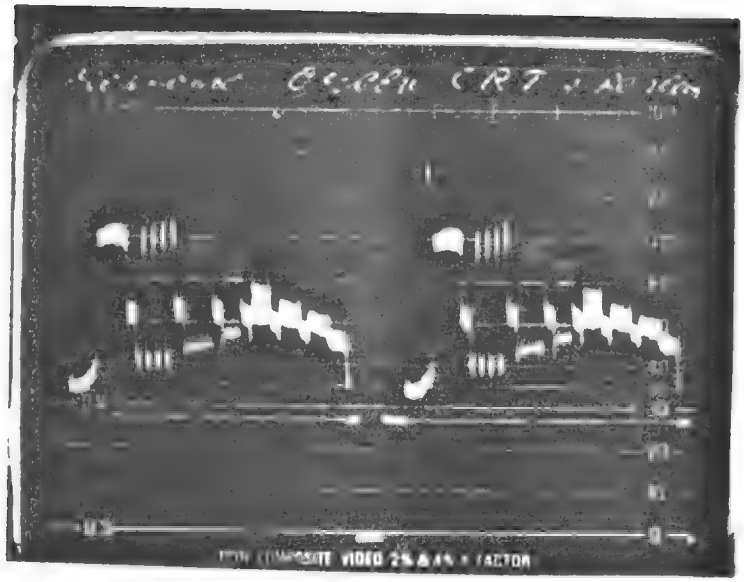


FIG 7. RESPONSE GREEN CRT.

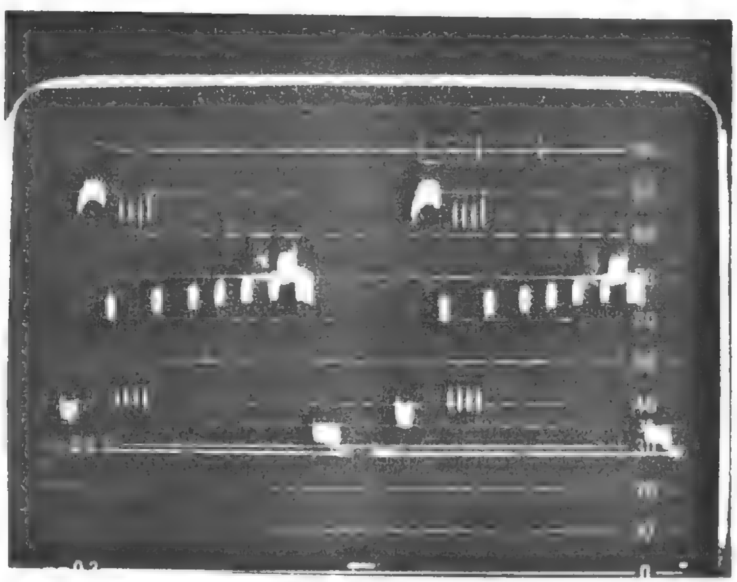


FIG 8. RESPONSE BLUE CRT.

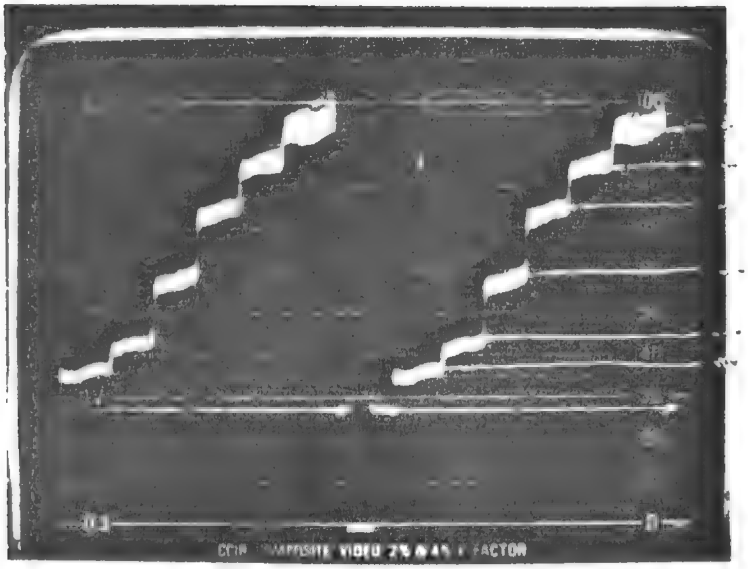


FIG 9. RESCAN LINEARITY.

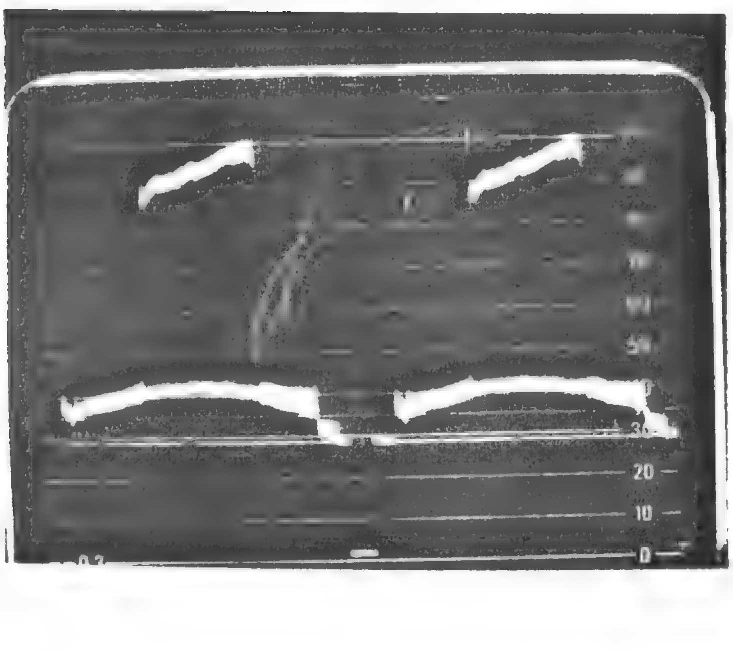
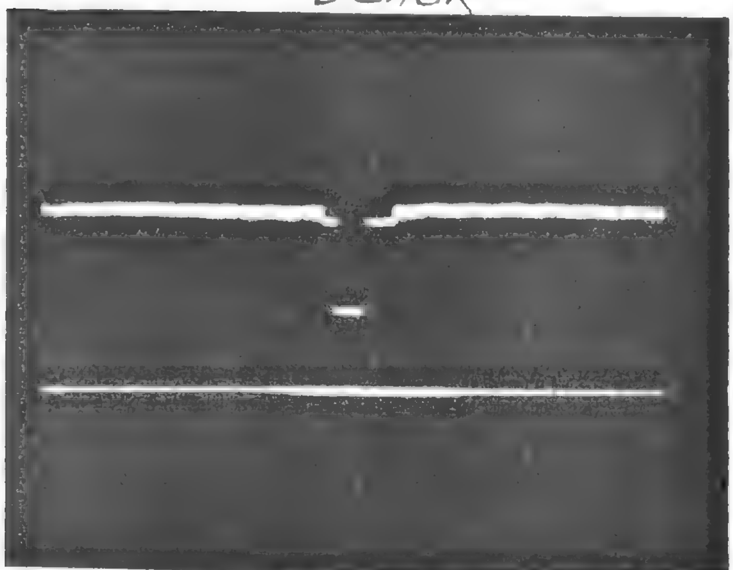


FIG 10. RESCAN H SHADING.

RESCAN ONLY.

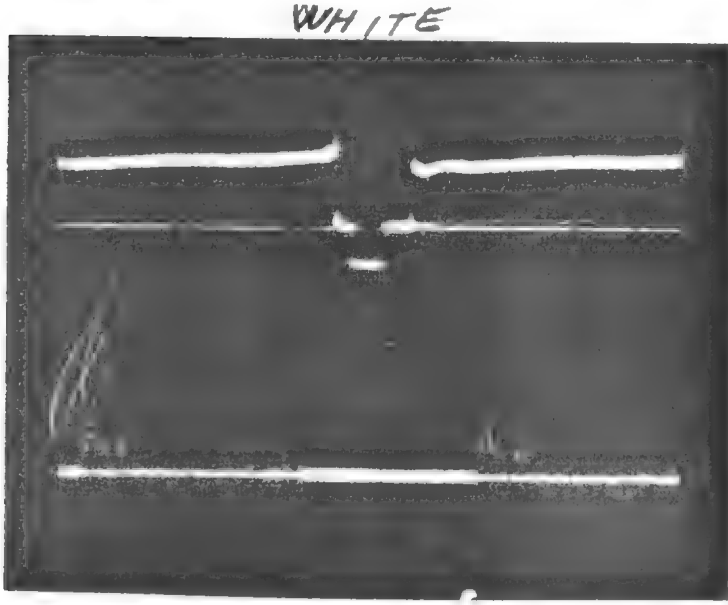
BLACK



Rescan only 10μS/cm LPF 4c MHz

FIG 11 . BLACK RESCAN NOISE.
S/N =51 DB

WHITE



.02 V/cm

FIG 12. WHITE RESCAN NOISE.

S/N = 45 DB

RESCAN ONLY

Rescan only

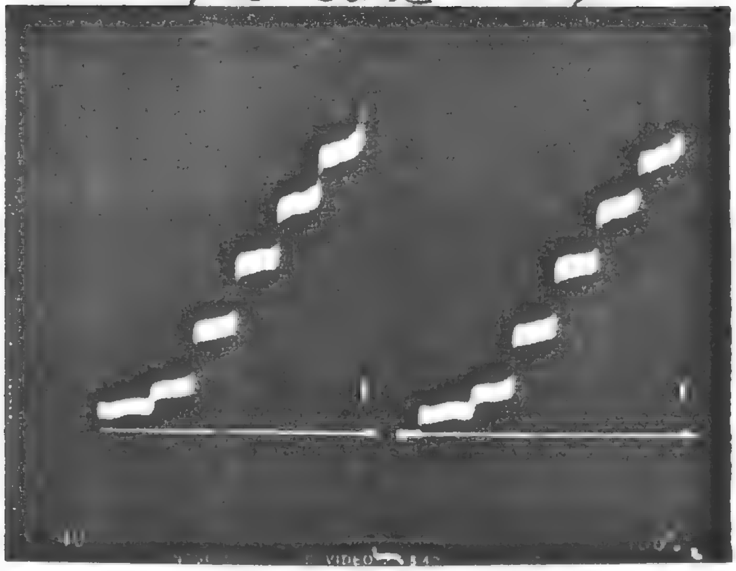


FIG. 13.

FIG. 14.

Rescan only

FIG. 15.

FULL VFX

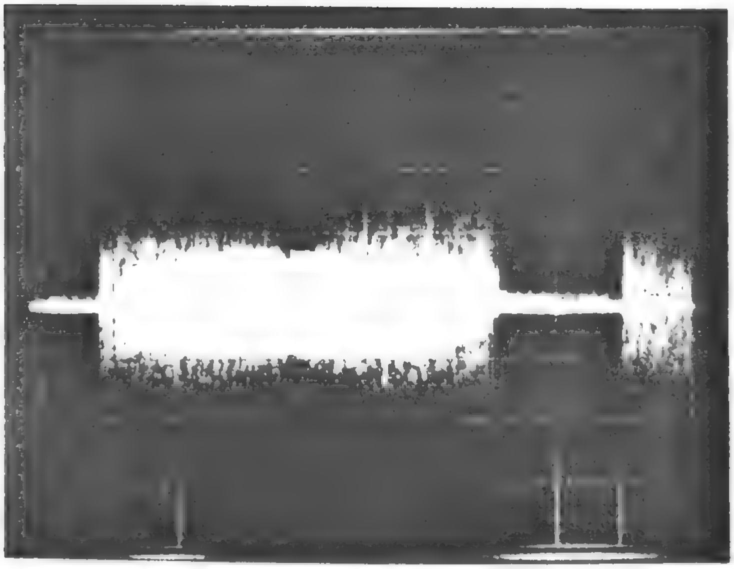
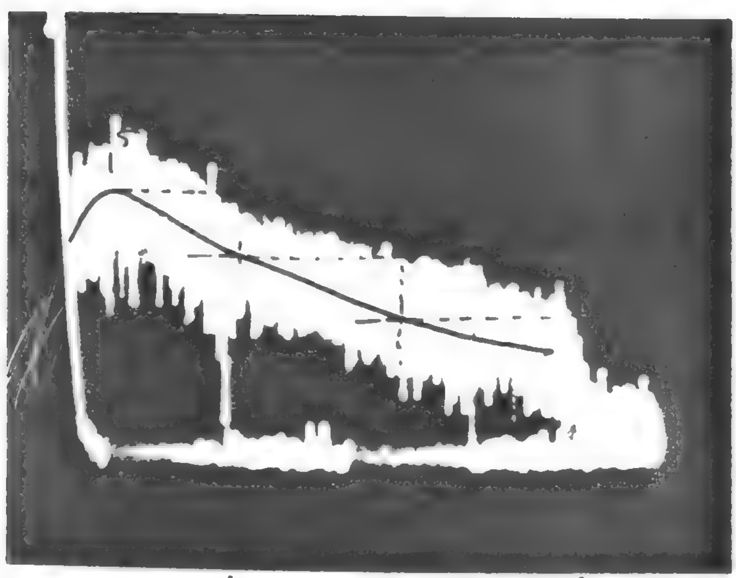


FIG 16. VFX OVERALL NOISE.

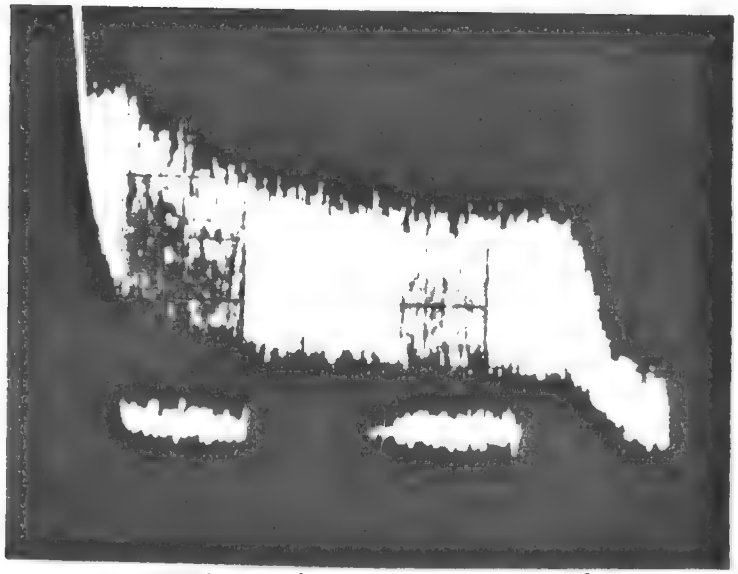


10 DB/CM 0.5 MHz/CM

FIG 17. VFX NOISE SPECTRUM.

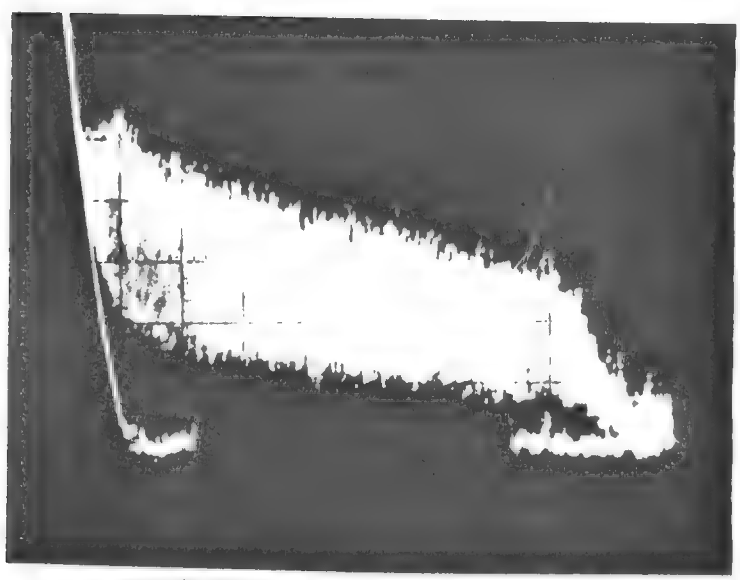
-6 db/OCTAVE

FULL VFX SYSTEM.



0.5 MHz /CM 10 DB/CM

FIG 18. BLACK SPECTRUM.



0.5 MHz /CM 10 DB/CM

FIG 19. WHITE SPECTRUM.

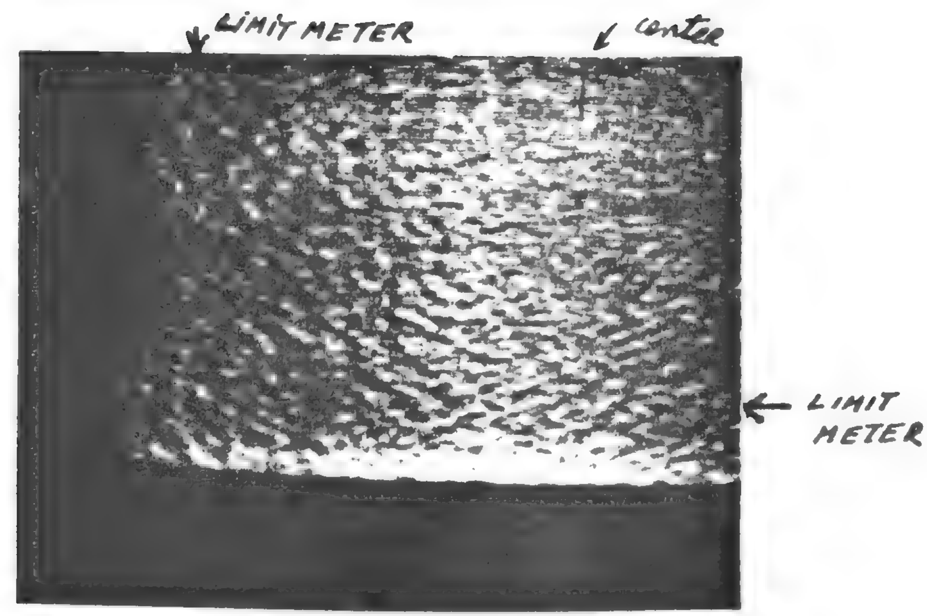
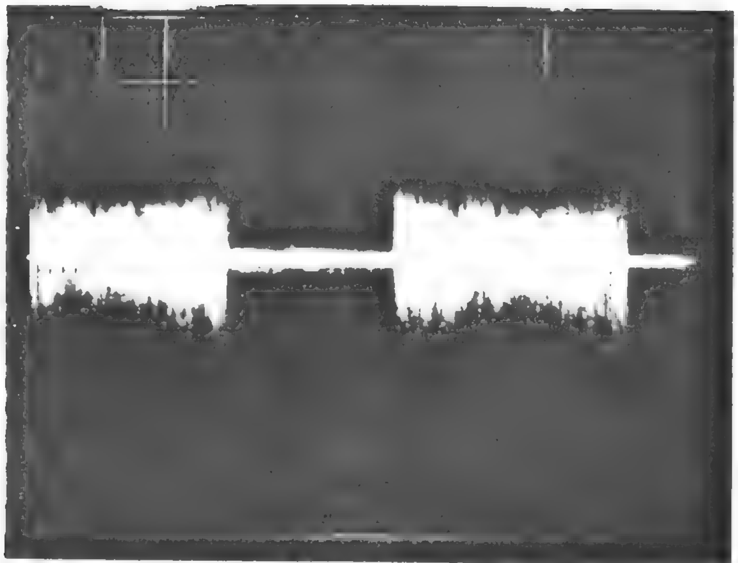


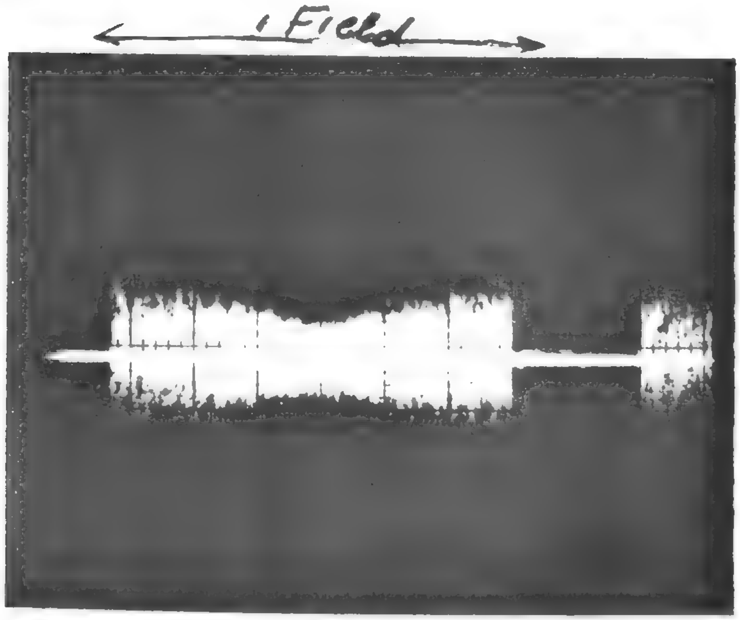
FIG 20. VFX.

WHITE FIELD - SCREEN APPEARANCE.



H scan

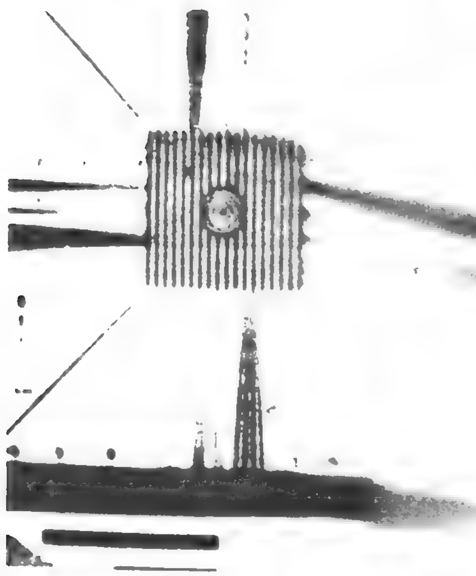
FIG 21. H SCANNING ONLY.
NOISE.



V scan

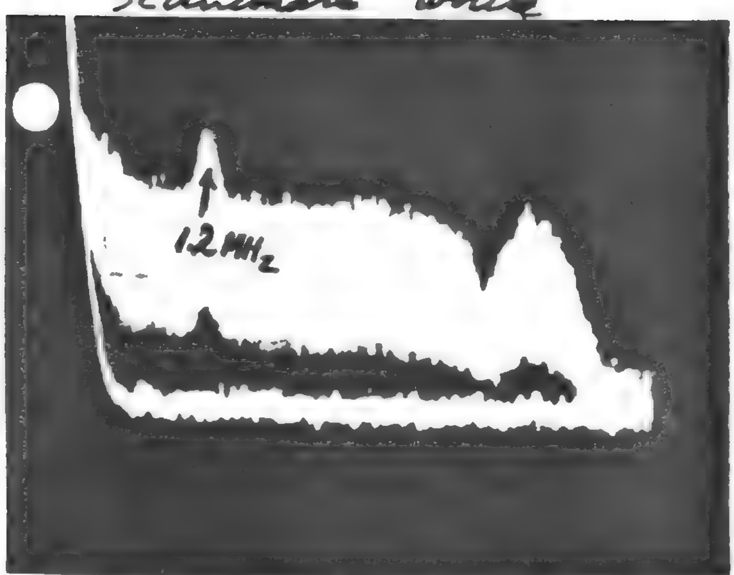
FIG 22. V SCANNING ONLY
NOISE.

S C A



F I G 2 3

Scanmate white



36.5 db

FIG 24. NOISE SPECTRUM.

SCANIMATE.

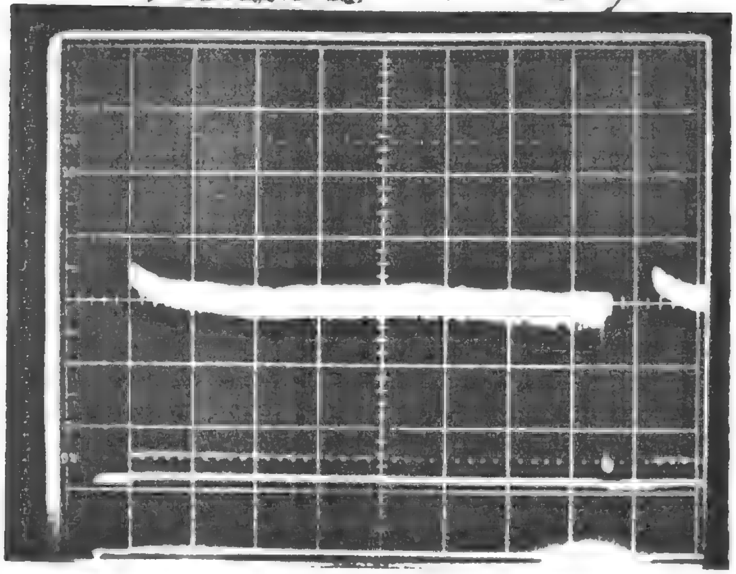
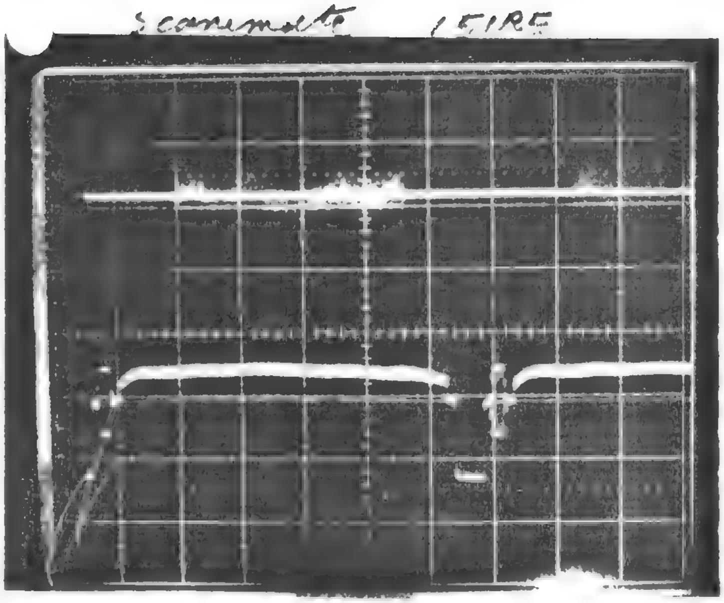


FIG 26. V SHADING.

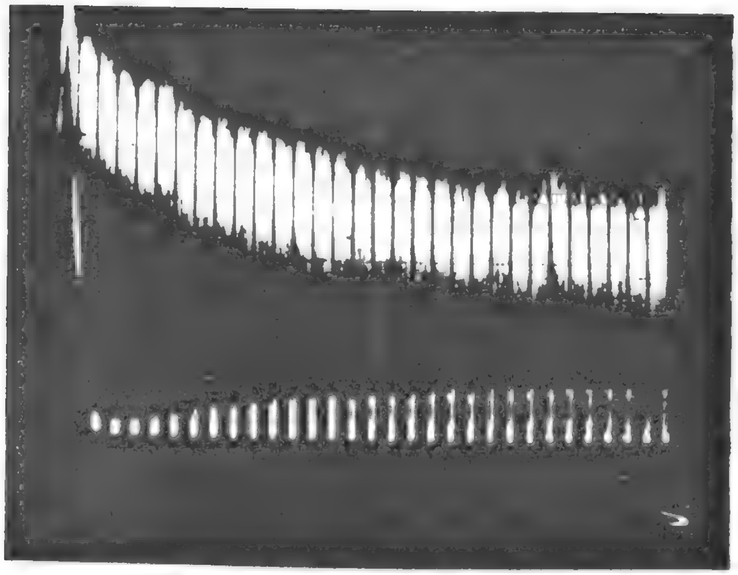


45db

FIG 32. BLACK NOISE.

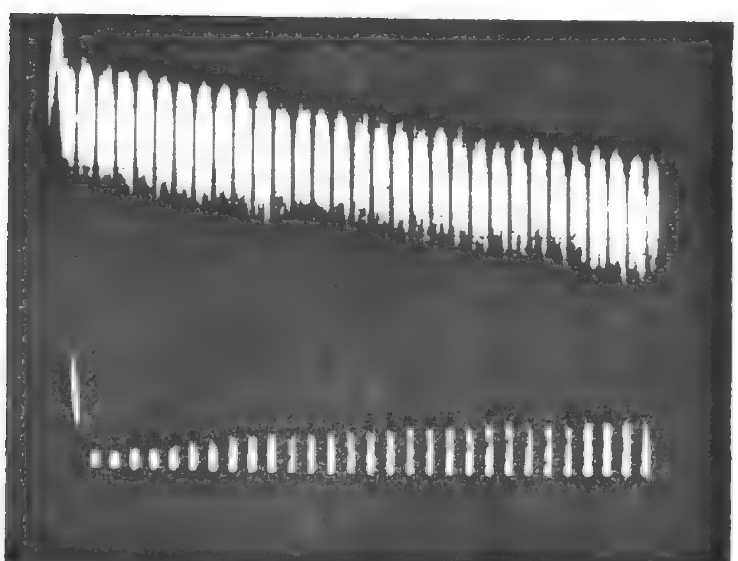
45db

FIG 33. BLACK NOISE SPECTRUM.



0.5 MHz/CM 10DB/CM

FIG 27. VCR V OUT.
NOISE SPECTRUM.



0.5 MHz/CM 10 DB/CM

FIG 28 VCR V MULTIPLIER OUT.
NOISE SPECTRUM.

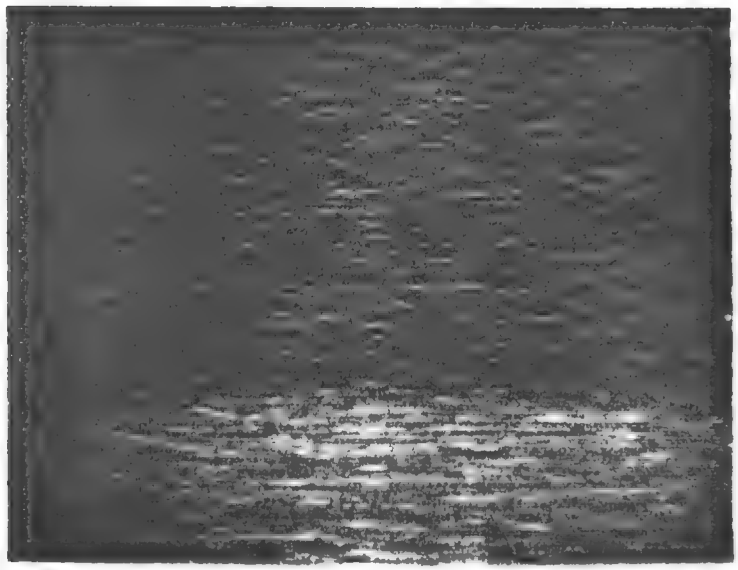


FIG 29. VFX SCREEN

NO PERSPECTIVE.

NEW MULTIPLIER.

FIG 30. VFX OUT. VROTATION: +1

S/N BLACK = 46 DB

FIG 31. VFX OUT VROTATION: -1

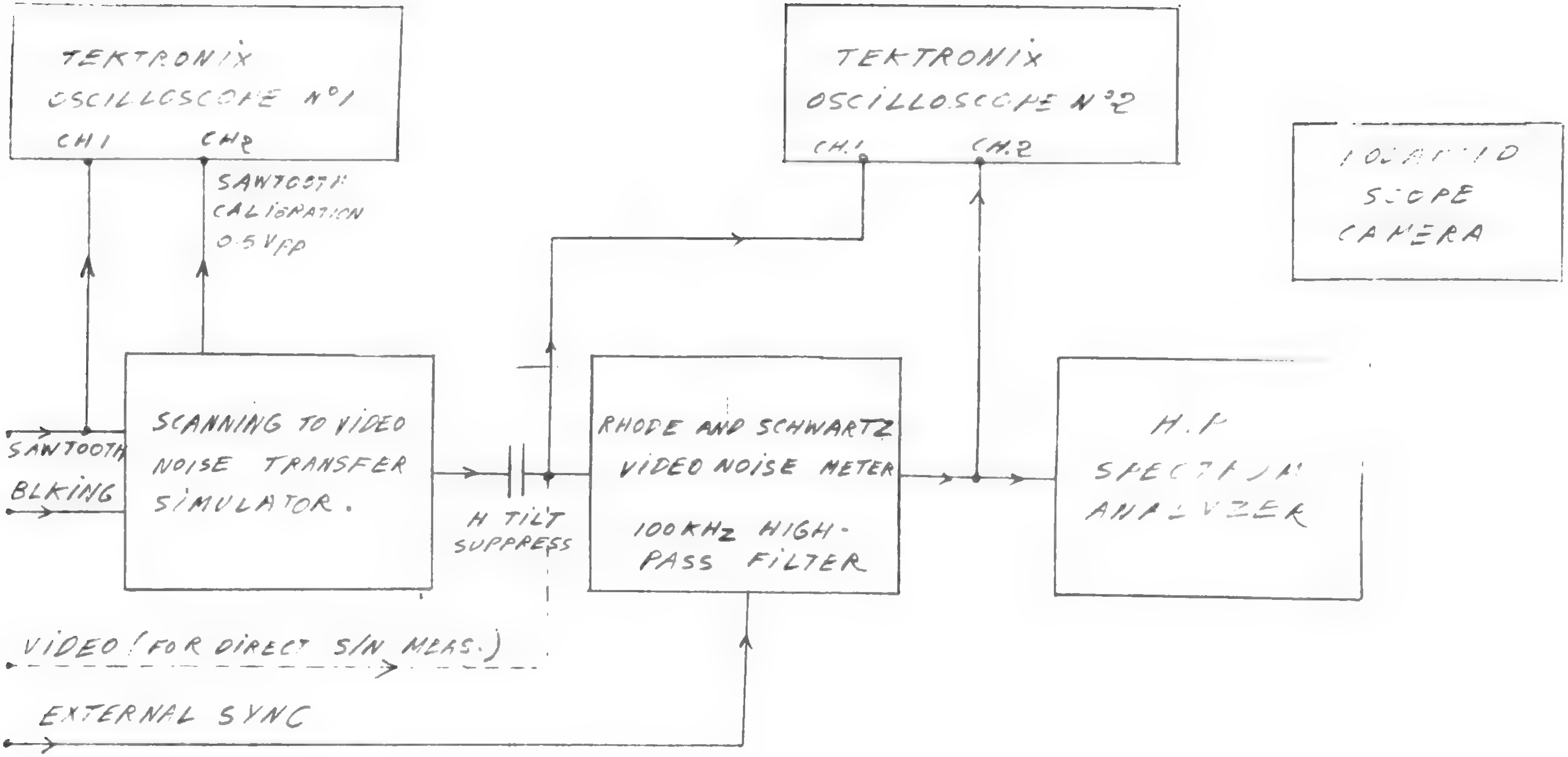


FIG 34. NOISE MEASUREMENT SET-UP.

YF 7-31-84

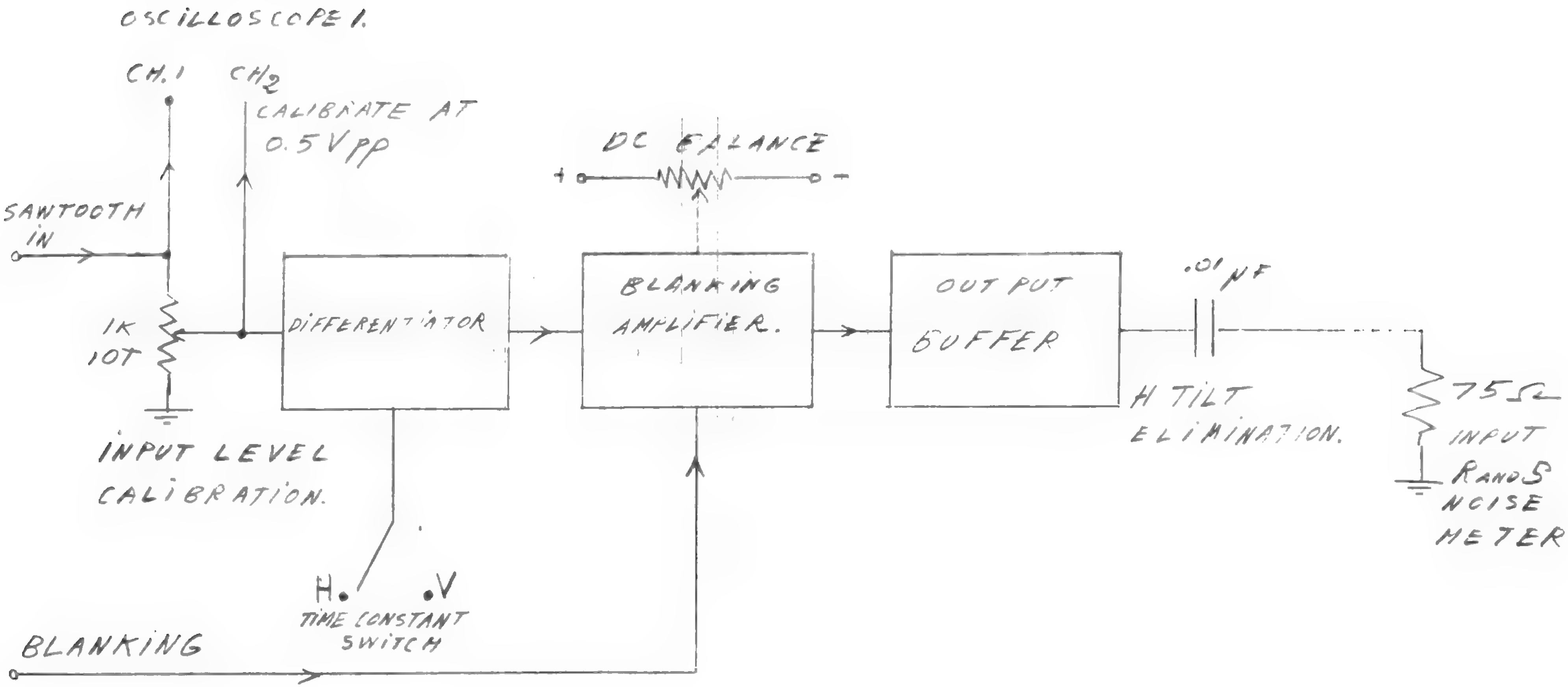


FIG 35. SCANNING/VIDEO NOISE TRANSFER SIMULATOR - BLOCK - DIAGRAM.

YF 7-31-84

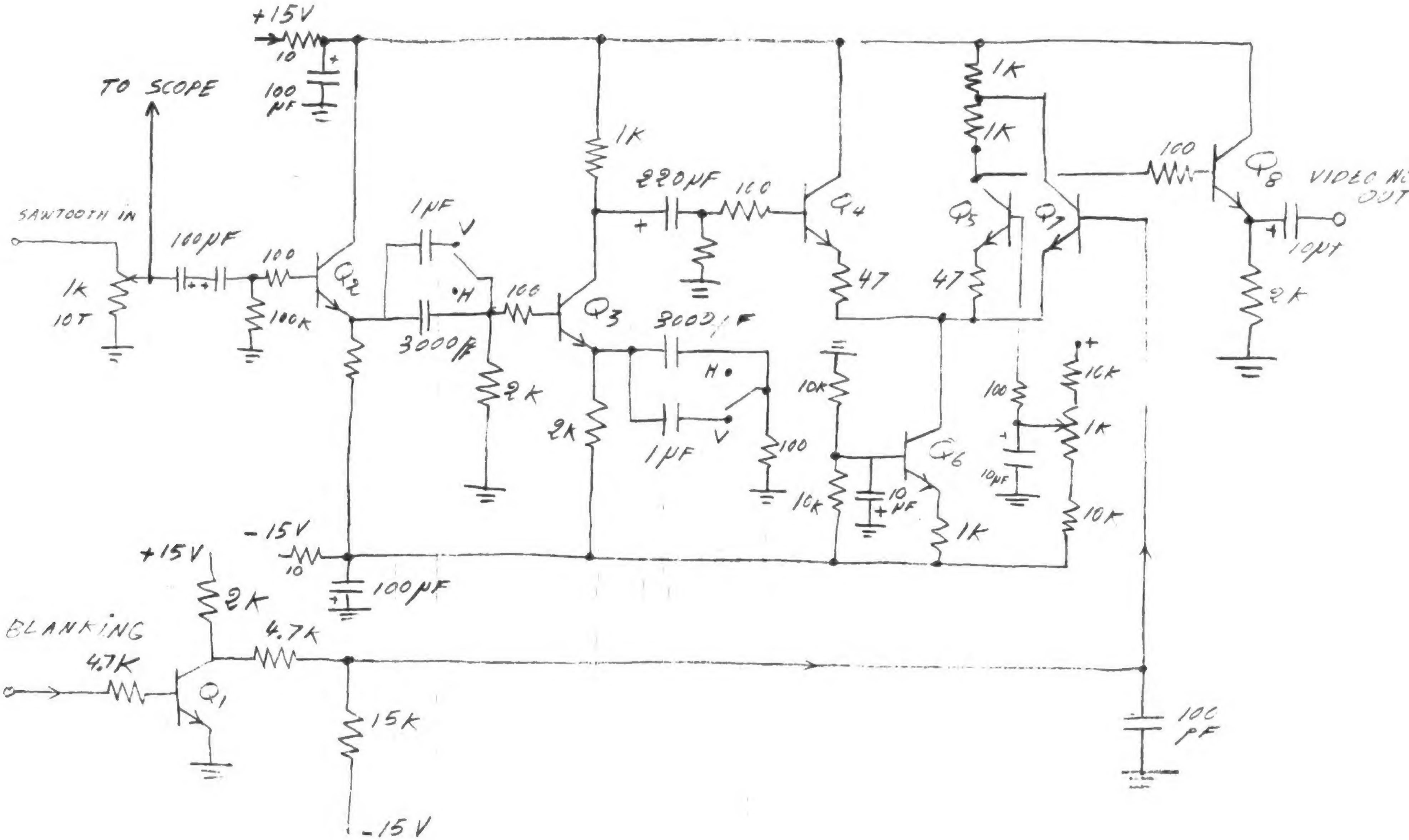


FIG 36. SCANNING-TO VIDEO NOISE TRANSFER SIMULATOR.

YF 7-31-84

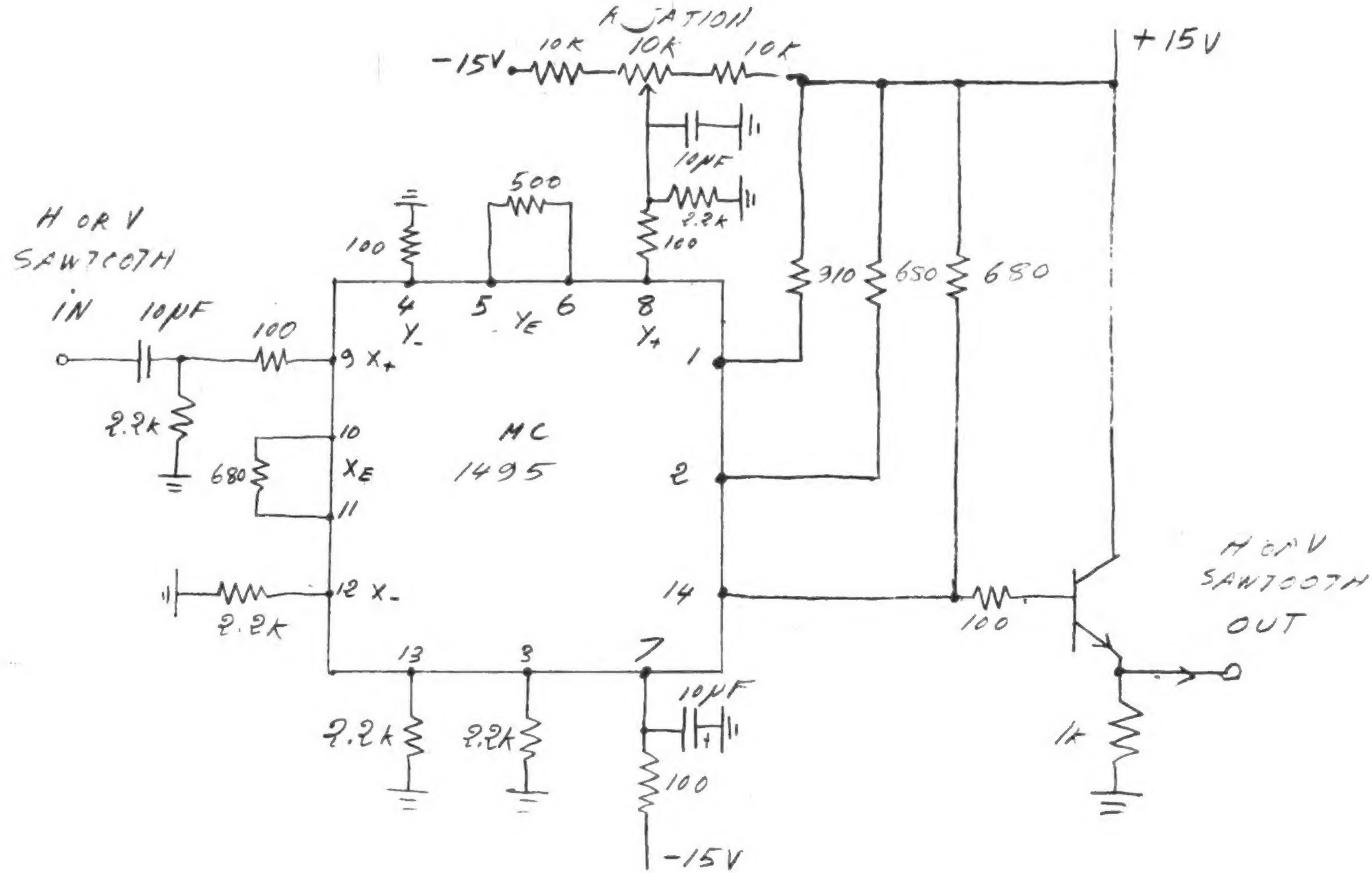


FIG 37. ROTATION SIMULATOR.

YF 7-31-84

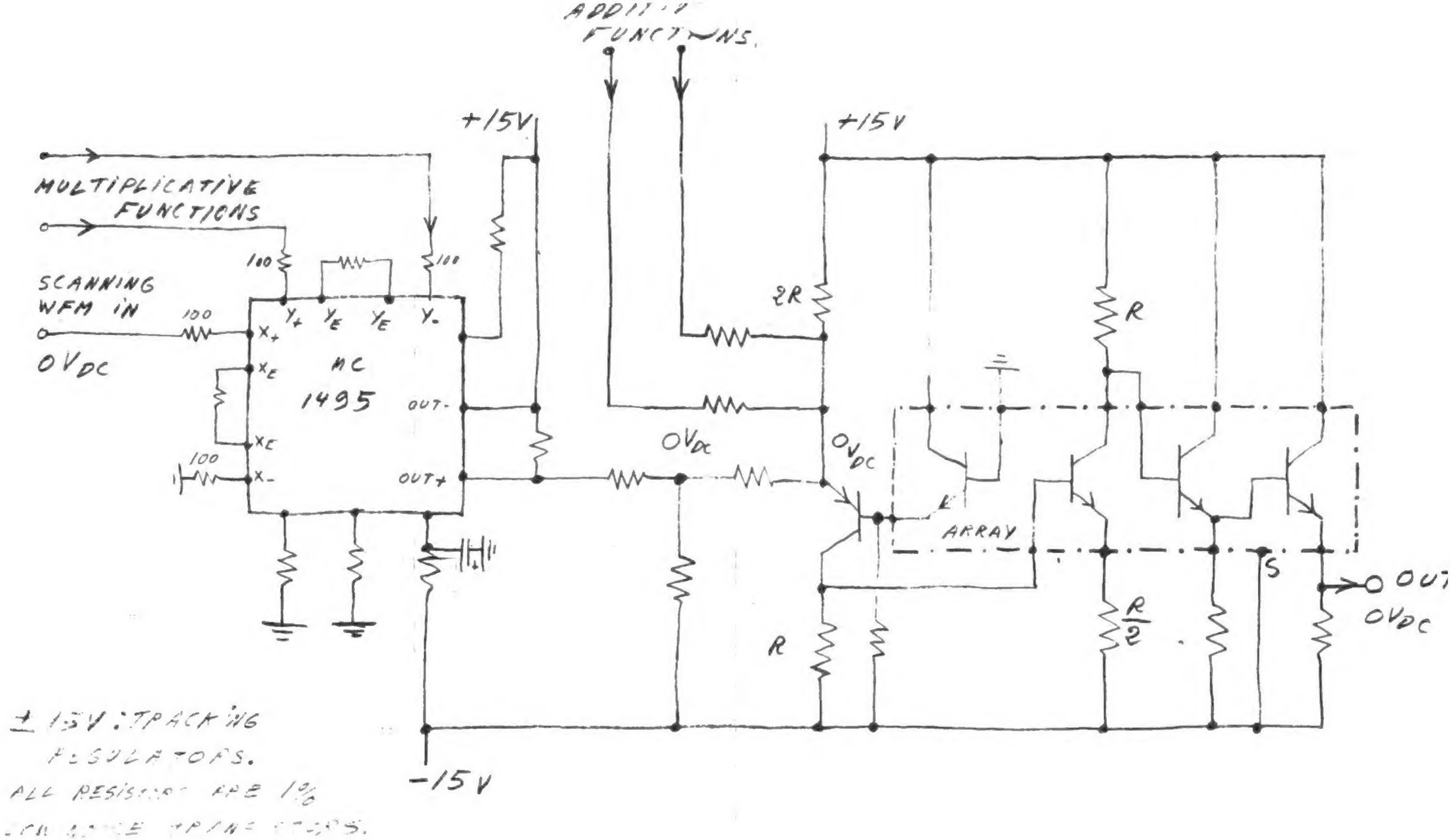


FIG 38. AN EXAMPLE OF A LOW DRIFT, LOW NOISE, DC OFFSET FREE, MANIPULATOR.

VF 7-31-84

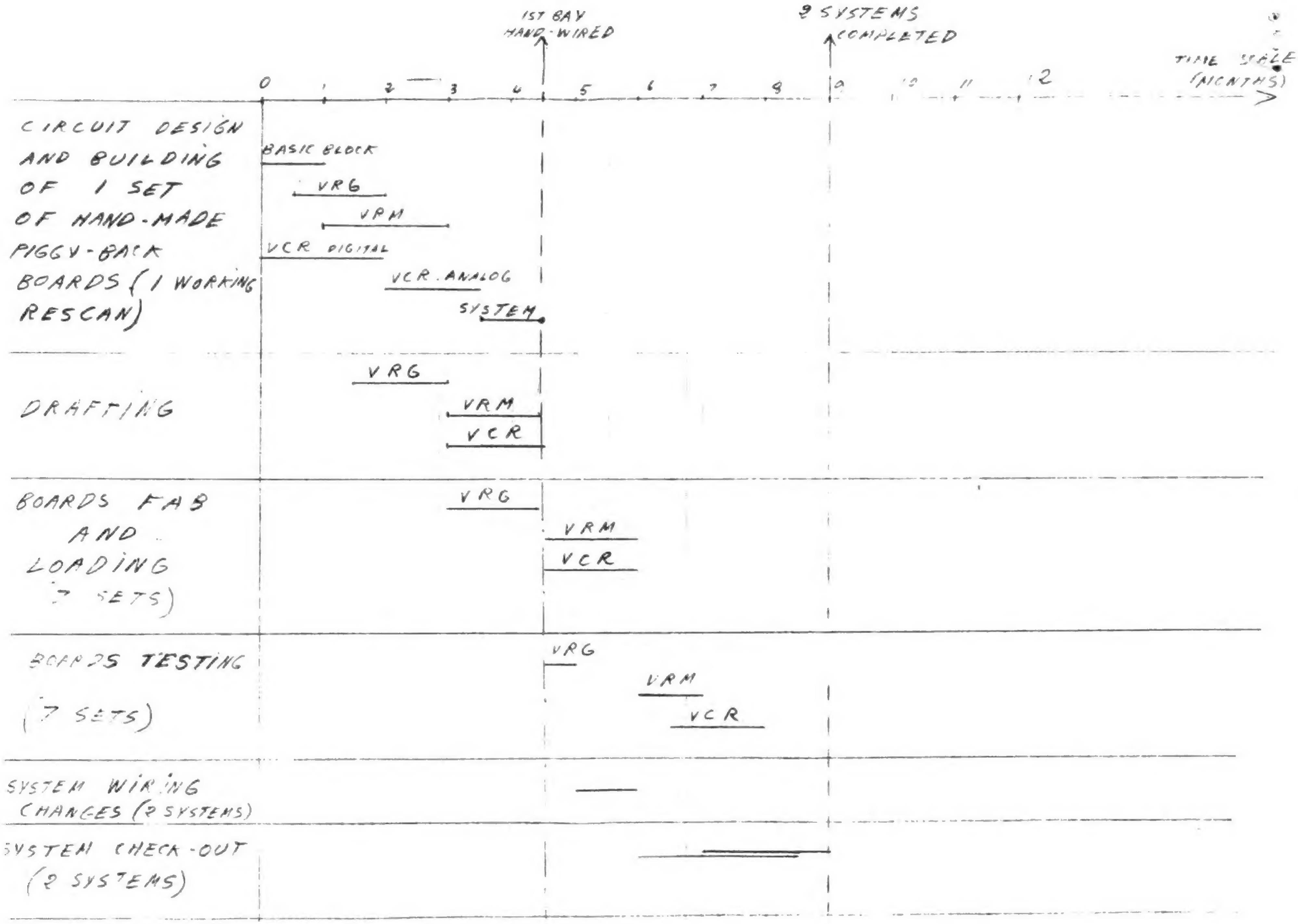


FIG 39 VERSEFX IMPROVEMENT PROGRAM.

YF 7-31-84